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Intertrial Influences in a Stroop-like Task

by

Daniel J. Pilon

(C)

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(SIGNED) Daniel J. Pilon

PERMANENT ADDRESS:

1830 Francoeur

Chomedey Laval

Québec

DATED October 12 1989

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Intertrial Influences in a Stroop-like Task submitted by Daniel J. Pilon in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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Date October 12, 1989

A Mary Fernande Smith et Lucille Pilon,

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Abstract

A Stroop-like task was used to determine the influence of semantic relatedness on mechanisms underlying attentional interference. Stimuli consisted of a target digit flanked by two distractors (e.g., '2 5 2'). Semantic relatedness, defined as arithmetic difference, was varied between distractor and target on a trial and between consecutive targets and consecutive distractors. The aim was to determine whether sematic relatedness influences the retrieval mechanisms involved in selecting and naming targets. One mechanism, target facilitation, increases the activation level of targets to make them more accessible for retrieval. A second, distractor suppression, reduces activation level of irrelevant information. Analyses of response latencies indicate that semantic relatedness influences target facilitation but not distractor suppression. These results imply that the two retrieval mechanisms are influenced differently by semantic relatedness and have implications for understanding retrieval and interference.

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Intertrial Influences in a Stroop-like Task

The selective nature of cognitive processing has been the focus of much research addressing how information is accessed in memory (e.g., Broadbent & Broadbent, 1977; Neely, 1976, 1977; Posner & Snyder, 1975; Treisman, 1977). The Stroop color-word task is a good example of a task used to investigate selective attention (see Dyer, 1973 for a review of Stroop literature). In Stroop-like tasks, two forms of information usually are integrated within one stimulus (e.g., a color name printed in a different ink color), and the individual is asked to respond to only one of the attributes. The general finding is that, when the two forms of information are in conflict (e.g., the word "green" printed in red ink), the individual experiences some form of interference when naming one attribute (i.e., ink color) but not when required to name the other (i.e., color word).

This asymmetrical interference effect initially was accepted as evidence that information was processed along a single centralized information-processing channel (Dyer, 1973; Posner & Snyder, 1975). According

to such a view, different information competes for access to this single channel, and the most rapidly processed information makes it through the channel first. This view has been challenged by Dunbar and MacLeod (1984) who presented words upside-down and backwards to reduce reading speed. They found that increasing the time required for word reading by reversing the spelling leads to interference from the ink color on word reading but does not eliminate the interference of word reading on color naming. The single-channel hypothesis would have predicted that interference should only occur with one stimulus at a time. More precisely, color naming should have interfered with reading, or reading with color naming, but both should not occur within one experimental condition because information is processed sequentially. Basically, the asymmetry of interference was not truly reversed. Such a finding discredits any explanation of the Stroop effect based solely on a single-channel, speed-of-processing hypothesis.

An alternative explanation has been proposed by Neill and Westberry (1987), who reported interesting

findings that can be interpreted as evidence that the speed-of-processing hypothesis is not sufficient to account for Stroop interference. Based on previous work (Neill, 1977, 1978), Neill and Westberry used a variation of the Stroop color-word task and examined response latencies as a function of relations among stimuli between trials. By examining residual effects of previous trials on subsequent trials, they found evidence that subjects seem to suppress distracting information in order to access the target efficiently on Stroop trials. Such a process provides an alternative to the speed-of-processing model. The present study was designed to identify possible facilitative and interfering effects in Stroop-like tasks that may result from information processed on a previous trial. The purpose of the present research was to bring together findings of studies using Stroop-like tasks and models of semantic or associative memory.

Facilitation and Interference in Stroop-like Tasks

Dalrymple-Alford and Budayr (1966) found that the overall time to name colors in a list of Stroop words was especially slow if each color corresponded to the

distracting word in the immediately preceding trial. Neill (1977, 1978) suggested that this effect may result from continued availability of activation after a response has been given and from cognitive operations, such as suppression, involved in response selection. To test this hypothesis, Neill (1977, 1978) and Neill and Westberry (1987) used stimuli similar to those used by Stroop (1935), that is, color words printed in various ink colors. For each stimulus presented, participants were required to name the ink color. Response times (RTs) were obtained for individual Stroop stimuli, and data were analyzed according to the relation between consecutive trials. Some of the conditions used by Neill (1978) and Neill and Westberry (1987) are illustrated in Table 1. Included were critical trials for which (a) the distractor (color word) matched the previous ink color ($Target_1$=$Distractor_2$), (b) the ink color (target) was identical to the previously presented distracting color word ($Distractor_1$=$Target_2$) and, (c) no information was repeated from the previous trial (unrelated). Neutral trials consisted of strings of Xs printed in the corresponding ink color. Data obtained

on the second trial of each pair of stimuli are pertinent because these trials differ only in terms of the information available from the preceding trial. Neill and Westberry (1987) also varied the time interval between a response and the onset of presentation of the next trial (Response-Stimulus Interval, RSI).

Neill (1977, 1978) found a decrease in response latencies on the second trial when the distracting information for this trial was a repetition of the target presented previously (see the first example in Table 1), as compared to latencies obtained with an unrelated trial. For example, saying "green" to the word BLUE printed in green took less time if preceded by the word RED printed in blue than the word RED printed in yellow. RSI was not manipulated in this study; the results observed were obtained when the subsequent trial was presented immediately after a response was given on the previous trial. The facilitative effects of a previous target on the subsequent trial will be called target faciliatation.

Neill (1978) assumed that the time necessary to retrieve a response depends on the number of concepts

activated by a display, as well as on the difference in activation levels between these concepts. He suggested that target facilitation occurred because repeated stimuli activated fewer concepts than did a pair of unrelated stimuli, for which an additional stimulus is presented. Hence, in the case of repeated stimuli, fewer activated concepts compete with the target and thus less processing time is required to select the correct response.

If fewer activated concepts require less processing time, then it should not matter which information is repeated. That is, repeating the previous target as the current distractor, as done by Neill (1978), or repeating the previous distractor as the current target should result in similar effects of reduced interference. Evidence against this interpretation was obtained by Neill and Westberry (1987), who found interference when the target on one trial was identical to the distractor in the previous trial (refer to the second example in Table 1). For example, the color "green" took longer to name if the preceding color word was GREEN printed in any color ink than if the preceding

color word was an unrelated color word (e.g., YELLOW printed in blue). The increased interference obtained when the previously presented color word is repeated as the ink color on the next trial was labelled distractor suppression by Neill and Westberry. These authors suggested that interference increased because the activation level of the distractor on the first trial was reduced, by suppression, to increase the discriminability of the target on this trial. They concluded that the suppression of distracting information was still in effect when the subsequent trial was presented. The suppression mechanism they proposed is based on the assumption that a correct response can be retrieved only when the difference in activation levels between target and distracting information is great enough to distinguish the target as the concept to select for response.

The results of these two studies imply that two mechanisms are involved in the selection of a response. Neill and Westberry (1987) proposed that selective attention consists of two mechanisms: a selective excitatory mechanism to process relevant information and

a selective inhibitory mechanism to process irrelevant information. The evidence for this interpretation rests with target facilitation found when a previous target is repeated (see the first example in Table 1) and with distractor suppression when previously distracting information is repeated as the subsequent target (see the second example). Given that processing of information on the first trial influenced latencies on the second trial, Neill and Westberry (1987) concluded that residual activation effects persist longer than the duration of a single trial.

Underlying this interpretation is the assumption that information is represented in memory in an organized network of concepts that can be activated either directly, by presentation of a stimulus, or indirectly, by association with other activated information (Collins & Loftus, 1975). Activation of information is assumed to be automatic in the sense that it occurs regardless of the relevance of the stimulus to the decision being made. The resulting activation of concepts influences which concept is selected for retrieval. This assumption is the origin of the

selective excitatory mechanism proposed by Neill and Westberry (1987).

Examining Neill and Westberry's (1987) data, it is possible to infer the time course of the effects of the selective inhibitory mechanism. Their results indicate that the effects of distractor suppression varies as a function of RSI. When comparing trials for which the target was a repetition of the previous distractor to trials preceded by unrelated color stimuli, it took subjects 10 ms longer to identify the target on the former trial than on the latter when trials were separated by a 20-ms RSI. This interference increased to 23 ms at 520-ms RSIs, decreased to 10 ms at 1020-ms RSIs and was completely eliminated (-8 ms) at 2020-ms RSIs. This pattern suggests that selective inhibition requires some time to develop. The fact that target information was accurately identified at every RSI suggests that initiating suppression is sufficient to respond. The initial increase in interference reveals that the distractor-suppression mechanism requires an undetermined amount of time to be fully operational. As suppression increases, interference on a subsequent

trial also increases. Neill and Westberry's data indicate such an increase from 20-ms RSI to 500-ms RSI. Once suppression has reached its maximum strength, the effects of suppression decay and interference on the subsequent trial decreases. The reduction of suppression over time is consistent with the hypothesis that suppression effects, like activation effects in research on semantic memory (e.g. Collins & Loftus, 1975), dissipate or are overridden by other processes at longer delays.

Neill's (1978) data are not as informative with respect to the development of target facilitation over time, because Neill did not vary the delay of presentation between trials. One possibility, which is similar to Neill and Westberry's (1987) interpretation of distractor suppression, is that target-facilitation effects occur because of residual activation from the previous trial. More precisely, the activation level of the previous target may be high enough to discriminate the target from other activated concepts and the target remains activated for some time. Given this residual activation, a concept may be identified more rapidly on

the subsequent trial and, consequently either be suppressed more rapidly if irrelevant or be named more rapidly if the target.

Such an interpretation of the two selection mechanisms suggests that responses to the first trial could be given before suppression had fully developed, but that suppression of activated concepts continues as the subsequent trial is presented. These results imply that activation levels of concepts in memory corresponding to the target and distracting information need not be maximally discriminable for a response to occur, but that suppression be initiated before a response can be selected for retrieval. In support of this conclusion, Neill and Westberry (1987) manipulated instructions and found that suppression effects were obtained under strict accuracy instructions but that a nonreliable trend in the opposite direction was obtained with speeded instructions. Neill and Westberry concluded that if a response is selected before the suppression process is completed, as expected under speeded instructions, then distracting information influences processing on the subsequent trial. The lack

of a suppression effect under speeded instructions provides additional evidence that suppression requires some time to develop; otherwise responses would have been slowed regardless of task instructions. No data have been published pertaining to the possible relations between target facilitation and RSI.

Neill's (1977, 1978; Neill and Westberry, 1987) work leads to two major conclusions concerning intertrial effects: Repetition of information on consecutive trials affects the processing on the subsequent trial, and the effect differs depending on the information that is repeated. Neither Neill and Westberry (1987) nor Neill (1977, 1978) determined whether the presentation of related, but not identical, information on subsequent trials would result in similar effects. More precisely, the question is whether changes in semantic or associative relatedness affect the magnitude of Stroop-like interference.

Issues Related to Semantic Memory Models

Questions related to semantic organization of information in memory are significant because results of studies using priming procedures usually are interpreted

to show that lexical information is stored in memory according to semantic or associative relatedness (e.g., McLeod & Walley, in press; Posner & Snyder, 1975; Rosch, 1975a, 1975b). In priming studies, a related cue usually is presented before a target. The more closely related two stimuli are to one another, the stronger is the priming effect of the cue on the target. For example, the word "doctor" will be retrieved faster if it is preceded by the word "nurse" than by the word "lamp". It is argued that more activation spreads, or activation spreads more rapidly, to closely related than to more remote information. Furthermore, the effects of priming have been reported to decrease with longer intervals between the prime and the target because activation decays over time (Neely, 1976, 1977).

Rosch (1975b) reported that colors are dimensioned according to semantic codes in ways similar to other lexical information. Thus, if priming studies reveal effects of semantic or associative organization with color stimuli, then the Stroop method used by Neill and Westberry (1987) might also reflect this representational organization, because Neill and

Westberry's (1987) task is similar to a priming task. The similarity lies in the fact that Neill and Westberry investigated the effect that processing a trial would have on processing of the subsequent trial, much like a prime on a subsequent target. Demonstrating that intertrial influences can be observed with nonidentical stimuli would have broader implications for the role of semantic organization in retrieval.

A second issue is directly relevant to the two retrieval mechanisms proposed by Neill and Westberry (1987). Neill (1978) provided evidence that responding to a target reduced the distracting influence of irrelevant information on a subsequent trial (i.e., target facilitation). In addition, Neill and Westberry (1987) reported that a target identical to an immediately preceding distractor is suppressed (i.e., distractor suppression). Unfortunately, these effects are interpreted without consideration to the other relations between the attributes of two consecutive stimuli. It is conceivable that the activation levels of concepts in memory are affected by the relations between any attributes presented on consecutive trials.

More precisely, target activation could precipitate processing of target and distracting information on the subsequent trial. If target activation influences the subsequent target, then latencies to respond to this latter target should be decreased compared to a trial not affected by target activation. Similarly, target activation could accelerate the rejection of distracting information on the subsequent trial and lead to more rapid suppression of the distractor. Analogously, suppression of the previous distractor could influence the activation levels of both the target and the distractor on the next trial. Distractor suppression should decrease the level of activation of both target and distractor on the subsequent trial, reducing interference if the subsequent distractor is affected or increasing interference if the subsequent target is affected.

To resolve both these issues, the present study is designed to test (a) whether target activation and distractor suppression are influenced by semantic or associative relatedness between stimuli presented on consecutive trials, (b) whether target activation

facilitates the rejection of distracting information and/or the identification of the target on the subsequent trial, and (c) whether the suppression process proposed by Neill and Westberry (1987) not only reduces the availability of the subsequent target but also influences the activation level of subsequent distractors. Stating the predicted effects in terms of semantic relatedness clarifies these predictions. First, if a distractor identical to the previous target is more easily suppressed than a remote distractor, then a distractor closely related to the previous distractor also is expected to be processed more rapidly. Such would be the case because more activation reaches the subsequent distractor if it is more closely related, resulting in more rapid suppression. In contrast, identification time of a target closely related to the target on the previous trial should be reduced compared to a target that is more remotely related.

Second, if the distractor-suppression mechanism influences the activation level of a subsequent distractor, then closer distractors on the subsequent trial are expected to interfere less with the

identification of the target than more remote distractors. In contrast, targets closely related to the previously suppressed distractor will lead to greater interference than more remote targets because the suppression is assumed to spread more strongly, or more rapidly, to closely related than remote targets. Thus, distractor suppression is expected to lead to different effects on latencies depending on which relation between attributes of consecutive trials is emphasized.

Selection of Stimuli and Task Analysis

These hypotheses can be tested if the semantic or associative relatedness between consecutive distractors or consecutive targets can be shown to be critical for the effects obtained. Color stimuli (ink colors and color names) may not be optimal to assess the semantic or associative relatedness between attributes of consecutive stimuli, whereas digits appear to be better suited for such an assessment. For example, there might be a wide variation in the semantic representation of colors, whereas numerical facts are well learned stimuli in adults and are expected to share uniformly well-

defined internal representations across individuals (Shepard, Kilpatric, & Cunningham, 1975). In addition, numerical facts generally are understood according to arithmetic relations or position on the number line (Siegler & Robinson, 1982), and lend themselves well to the investigation of semantic or associative relatedness within a network of memorial information. It would be difficult to frame color stimuli according to similar characteristics. Finally, numerical stimuli have been shown to produce facilitative and interfering effects under various priming situations (Ashcraft & Battaglia, 1978; Flowers & Wilcox, 1982; Hamann & Ashcraft, 1985; LeFevre, Bisanz, & Mrkonjic, 1988), whereas color stimuli have been reported to be primed only by category names (Rosch, 1975b). Thus, numerical stimuli, rather than color stimuli, were used to ensure that critical stimulus attributes were processed in similar ways.

In the present study I used the flanking task of Flowers and Wilcox (1982), which is similar in several important respects to the color-word Stroop task. In this flanking task, a target digit was flanked on both sides by a different digit. For example, the target "5"

was flanked by the digit "8" on both sides. The participant's task was to name the middle digit as quickly and as accurately as possible. Flowers and Wilcox found Stroop-like interference in which incongruent trials (e.g., 3 2 3) took longer to process than congruent trials (e.g., 2 2 2) or neutral trials (e.g., # 2 #).

In the present study, three-digit displays were presented in which consecutive targets and consecutive distractors varied in the numerical differences between digits. Numerical differences between distractor and target within a trial also were varied systematically. These numerical differences were controlled to determine effects of semantic or associative relatedness between digits in consecutive trials. To replicate Neill's methods partially, RSI varied from 40 to 2040 ms. Based on research carried out by Neill (1978; Neill & Westberrry, 1987) and Lowe (1985), RSIs were selected to determine the course of activation and suppression over time.

Assuming that the strength of activation and/or suppression depends on semantic relatedness between

concepts and that semantic relatedness between digits is inversely related to the distance on the number line, then the magnitude of the effects are expected to vary as a function of the numeric distances between consecutive trials. The closer the subsequent information, the greater the effect carrying over from the previous trial. Activation spreading from the digits presented on the first trial should increase activation of closely related digits, compared to more remote digits, presented on the second trial.

Target activation should increase activation levels of both the target and flanker on the subsequent trial. For both situations, response latencies to name the target should be reduced. For example, the trial '2 3 2' preceded by the trial '1 4 1' is expected to result in faster response time to the target '3' than if it is preceded by '1 6 1' because the previous target '4' is closer to the target to be named (i.e., '3') than is the target '6'. Consecutive trials for which the targets are more closely related should result in faster processing of the target on the second trial, thereby reducing the time to name the target. Similarly, a

previously processed target should accelerate processing of a closely related flanker on the subsequent trial compared to a more remote flanker on this same trial, and result in less interference between the flanker and target on this trial. Using the previous example, the previous target is more closely related to the flanker on the second trial (i.e., '2') than is the previous target '6', resulting in faster suppression on the second trial.

Inhibitory effects ensuing from suppression of activation associated with irrelevant information presented on the first trial also are expected to vary as a function of the numeric distance between digits involved. Distractor suppression is expected to reduce the activation levels of target and flanker on the subsequent trial. For example, the trial '2 3 2' preceded by '1 4 1', compared to '2 3 2' preceded by '7 4 7', is expected to result in greater suppression spreading from the flanker '1' than the flanker '7' to the target on the second trial (i.e., '3') because '1' is more closely related to '3' than is '7'. For reduced activation of the target, the effect is expected to

increase response times. A previous flanker closely related to the current target should increase the time necessary to access this target (similar to Neill's distractor-suppression effect) compared to a similar trial for which the same information is more remotely related. For reduced activation of the flanker, decreased response latencies are expected. In contrast, closely related consecutive flankers should lead to reduced interference on the following trial because the flanker on the second trial is affected by the suppression of the previous flanker. For the trials presented on the previous example, the previous flankers '1' and '7' are expected to yield more suppression and less suppression, respectively, of the flanker on the second trial (i.e., '2').

To summarize, participants were required to name a target digit from a display of relevant and irrelevant digits. Intertrial factors varied systematically in the arithmetic differences between target and distractor. Accuracy and latency of response are postulated to be a function of the difference in activation levels between the flanker and target on the target trial. More

precisely, the activation level of each digit in the target trial is presumed to be the sum of residual activation from the previous trial and activation generated by the presentation of the digit on the subsequent trial. The difference in activation levels between the target and flankers presumably determines the availability of the target for retrieval as a response: the greater the difference, the greater the availability of the target and the faster the retrieval of the response.

Method

Materials

The stimuli consisted of a target digit flanked on both sides by a different digit (e.g., '5 9 5'). Arabic numerals from 1 through 9 were used. Of the 36 possible combinations of different target and flanker digits, only those for which the arithmetic difference was equal to or smaller than 5 were used because few combinations of digits have larger differences. The numerical difference between the target and the distractor on a trial will be referred to as the within-trial distance (W_{n-n}, where n refers to a trial number). For example,

a first trial "2 3 2" would be categorized as $W_{1-1} = 1$ (i.e., 3 - 2), and the following trial "7 2 7" would be categorized as $W_{2-2} = 5$ (i.e., 7 - 2).

Following Neill and Westberry's (1987) method of categorizing trials on the basis of relation to the previous trial, triplets were paired to form consecutive trials. Two sets of 525 trials were generated for which the arithmetic differences between consecutive targets ($T_{n-(n-1)}$) and consecutive flankers ($F_{n-(n-1)}$) were controlled. For purposes of balancing the size of arithmetic differences, the selection of stimulus triplets was constrained by the criterion that differences for W_{n-n}, $T_{n-(n-1)}$, and $F_{n-(n-1)}$ were equally distributed among small (±1), medium (±2 or 3), and large (±4 or 5) differences. For example, the trial "2 3 2" preceded by the trial "4 6 4" would be categorized as $W_{2-2} = 1$ (i.e., 3 - 2), $T_{1-2} = 3$ (i.e., 6 - 3) and $F_{1-2} = 2$ (i.e., 4 - 2). When controlling numeric distances betweeen consecutive targets and consecutive flankers, the cross-relations ($T_{n-1}F_n$ and $F_{n-1}T_n$) are determined.[1]

The three levels of each numeric variable were

combined to form 27 conditions [$3(W_{2-2})$ X $3(T_{1-2})$ X $3(F_{1-2})$]. Two triplet combinations from each condition were assigned to one of three presentation delays between trials (RSIs of 40, 200, and 500 ms), for a total of 54 trials per RSI (162 trials). Once the stimuli had been selected, a list of trials was generated with the constraints that no identical digit was repeated on consecutive trials and no more than three consecutive RSIs were identical. Using these constraints made it nearly impossible to generate a list of stimuli without inserting filler trials to ensure constraints were not violated. Filler trials consisted of triplets similar to trials defined by the numeric distances described above, but no data were obtained for analyses on these trials. Thirteen filler trials were added among the beginning and end trials of each block, resulting in 175 trials per block. Three blocks of trials were generated for a total stimulus list consisting of 525 trials.

Two presentation formats were used. In the continuous format, three blocks of 175 trials were administered to participants. In the paired format, six

blocks of trials (1050 trials) were presented with the added feature that every other trial was preceded by a 2040-ms RSI. Because Neill and Westberry (1987) reported that suppression effects had dissipated completely two seconds after a response, this manipulation ensured that only one trial was presented within the time necessary for suppression effects to dissipate. In order to allow direct comparison of the two presentation formats, the first three blocks were presented twice. In the first three blocks, RSIs for odd-numbered trials were replaced with the 2040-ms RSI, and in the last three, 2040-ms RSIs were assigned to the even-numbered trials. This manipulation was reversed for half of the participants. In this manner, both presentation formats consisted of the same trials at each of the short RSIs, and all trials were presented at the longer RSI for the six-block paired format.

A second stimulus list was generated by reversing the flanker and target on every trial. In this manner, the relations between consecutive trials were not completely preserved, but the combination of relations remained highly similar across stimulus lists.

Presentation format, stimulus list, and the assignment of 2040-ms RSI to even- or odd-numbered trials were between-subject variables. All other factors were within-subject.

A practice block consisted of one triplet from each combination of numeric distances (27 trials), equally distributed across RSIs. Practice trials consisted of stimulus triplets not used in the experimental blocks to ensure participants did not become differentially familiar with some combinations of digits. The same RSIs were used for practice as for experimental trials to familiarize participants with presentation components of the task.

Statistical independence among independent variables is important if conclusions are to be drawn about the role of semantic or associative relatedness between digits. Correlations between the three independent variables counterbalanced by design (see Appendix 1) were generally low and unreliable. No assumptions were made that the cross-relations were independent; in fact they were interrelated statistically (see Table 2 and Footnote 1) but not

consistently related to the other variables. The degree of multicollinearity between the cross-relations is relatively low (see the correlations of T_1F_2 and F_1T_2 in Table 2); thus, any confounding between indices of target activation and distractor suppression should be minimal (see Cohen & Cohen, 1983). For purpose of analyses, the independent variables were indexed in three ways: (a) by the differences between the digits for each numeric variable (e.g., the arithmetic difference between consecutive targets), (b) by grouping the differences according to the sizes used to counterbalance the stimulus set (i.e., small, medium, and large), and (c) by transforming logarithmically the differences of each numeric variable. The logarithmic transformation was carried out to assess the possibility that activation and/or suppression spreads in a nonlinear manner as a function of semantic or associative distance, such that the rate of spread is slower at greater distances (Ashcraft, 1987). These alternative methods of indexing independent variables did not significantly alter the correlations among variables (compare Table 2 and Appendix 1).

Procedure

Presentation and timing procedures were controlled by microcomputer. Finley's (1989) tachistoscopic-emulation functions were used to synchronize presentation with timing of the vertical-retrace signal. RSIs were measured to include the time necessary for the cycle of the vertical-retrace signal to be complete; error on RSI was less than 1 ms. Participants were tested individually. They were seated approximately 0.7 m in front of a CRT screen. The width of the display subtended 1.1° of visual angle horizontally and 0.3° vertically.[2] A microphone attached to a headset was adjusted on the participant's head. Reaction times were recorded via the voice-key. Response accuracy was recorded manually by the experimenter.

After task-specific instructions had been given, a block of practice trials was administered three times. Participants were instructed to name the target digit of each stimulus display as quickly and as accurately as possible. The first block was used to familiarize participants with the rate of presentation of trials. The second was used to adjust the voice-actuated relay

connecting the microphone to the microcomputer. The last practice block was administered to train participants on the experimental task.

For both practice and experimental trials, participants were told when the first trial would appear on the screen. Stimuli remained on the screen for 50 ms (see Lowe, 1985). A blank screen replaced the stimulus. Once the participant had responded to the stimulus, the next trial was presented after a predetermined RSI. This procedure was repeated until the participant had completed a block of trials. A message then appeared on the screen indicating the end of a block of trials. After practice blocks, participants were asked if they had any questions. After experimental blocks, participants were instructed to rest for a short while. The next block was initiated when the participant was ready to continue.

Subjects

Sixteen undergraduate students (8 males and 8 females) participated in the study in exchange for course credit. Half of the females and half of the males were presented trials under the continuous

presentation format. The others were presented paired trials. Data from two extra female students were not used because of equipment malfunction. The median age was 19:5 (years:months) for females and 20:5 for males.

Results

Analyses were conducted to determine whether information activated on a trial affects processing of information presented on a subsequent trial. More precisely, the purpose of the analyses was to identify intertrial excitatory and inhibitory effects. Multiple linear regressions were conducted separately for accuracy and latency of response to assess possible effects of activation and/or suppression as a function of the numeric distance, or arithmetic difference, between pairs of digits presented on consecutive trials. Partial support for the experimental predictions was obtained, namely, the distractibility of a flanker on the identification of a target decreased as the numeric distance between the flanker and the previous target increased.

Intertrial Influences for Latencies and Errors

Multiple linear regressions were carried out on

mean error rates and mean latencies for correct trials across subjects to test whether numeric distances between trials influenced the two retrieval mechanisms proposed by Neill and Westberry (1987). The independent variables included in the analyses were the numeric factors counterbalanced by design (numeric distance between consecutive targets, between consecutive distractors, and between target and flanker within a trial), as well as the cross-relations. The cross-relations were included because they presumably would reflect effects of activation and suppression. Assuming an additive model of activation and suppression precludes statistical interactions among these independent variables. Median latencies for each subject were computed for each combination of the independent variables, and means of medians across subjects were subjected to regression analyses. Data were excluded from analyses if the voice-key failed to close or closed before the participant responded (2.3% of all trials). Means are presented in Figures 1 to 5 for each of the five independent variables as a function of RSI. Similarly, error rates were averaged across

subjects for each combination of the independent variables and subjected to regression analyses. Because error rates were quite low (less than 5% at any RSI for either presentation format), the results of their analyses must be interpreted with caution.

Regression analyses were performed separately by RSI because the two retrieval mechanisms investigated were expected to behave differently as a function of delay between trials. The independent variables were indexed in three different ways because of different theoretical positions held with respect to representation of numerical information. Because the analyses of grouped, logarithmically transformed, and actual numeric distances yielded essentially the same pattern of results, only the results of data indexed by actual numerical distances are reported. Results of the two other sets of analyses are presented when they diverge from the pattern for actual numeric distances.

Results of regression analyses are presented separately for each presentation format, continuous and paired. Data from these two formats were analyzed separately because one-way ANOVAs for each RSI indicated

reliable differences in mean latencies between presentation formats: For 40-ms, 200-ms, and 500-ms RSIs the differences were 32.9 ms, $F(1,256) = 6.7$, $p = .01$, 40.2 ms, $F(1,247) = 8.1$, $p < .01$, and 47.8 ms, $F(1,271) = 12.3$, $p < .001$, respectively.

Initially, regressions were carried out in which all valid data points were included. Examination of standardized plots of residuals against combined independent variables indicated that some outlying data points unduly influenced the results of the regressions. Data points that were more than three standard deviations from the overall mean at each RSI were removed (one at each RSI was removed), and the data were re-analyzed. Summaries of the multiple linear regressions are presented in Tables 3 to 6.

40-ms RSI. For continuous presentation (see Table 3), latencies were accounted for by the numeric distance between consecutive targets. Regression coefficients for this relation accounted for about 3% of the variance. For each increase in numeric distance between consecutive targets, latencies increased by 17 ms. Marginal effects included the numeric distance between

consecutive flankers and the numeric distance between a flanker and the target preceding it. Marginal effects, in general, will not be discussed unless they relate to patterns of results obtained with other experimental conditions. A point in case is the numeric distance between a flanker and the target immediately preceding it, the effects of which will be addressed in a later section.

Error rates with continuous presentation were reliably related to the arithmetic difference between a target and the flanker that preceded it, decreasing 0.6% for each increment in numeric distance between these digits. This factor accounted for 4% of the variance in error rates. These results indicate that the accessibility of a target is increased by closely related previous targets, as indicated by response latencies, but also is decreased by closely related preceding flankers, as indicated by error rates.

Only 9% and 7% of the total variance is accounted for by the independent variables entered in the regressions on latencies and error rates, respectively. The low multiple $\underline{R}^2$s obtained in this study are

discussed in a later section.

For paired presentation (see Table 3), latencies and error rates were not reliably related to numeric distances between pairs of digits presented on consecutive trials, even though the multiple $\underline{R}^2$ for latencies was statistically reliable ($\underline{R}^2 = .09$). However, latencies were marginally related to the numeric distance between a flanker and the target preceding it ($\underline{p} < .10$), the importance of which will be understood better when the results for the other delays are presented. Visual inspection of the plot of residuals against predictors revealed no patterns in the distribution of residuals. Results for latencies and error rates otherwise were not affected by categorization of independent measures, except when the data were grouped according to magnitude as per the method used to generate the stimulus lists. Error rates for grouped data (see Appendix 2-A) were best accounted for by the numeric magnitude between a target and the flanker that preceded it ($\underline{b} = -4.9\%$).

200-ms and 500-ms RSI. Regression analyses on latencies for continuous presentation (see Tables 4 and

5) indicate that latencies were related reliably to one numeric-distance factor at 200-ms RSI, despite the fact that the multiple $\underline{R}^2$ was not reliable. The arithmetic difference between a flanker and the target that preceded it reliably decreased RTs by 19 ms for each increase in distance between these two digits, accounting for 5% of the variance in latencies. Interestingly, the same numeric-distance factor is marginally reliable at 500-ms RSI. No numeric factors were related to error rates at either delay. The distributions of residuals revealed no obvious pattern of distribution, again indicating that linear combination of the predictors best describes the obtained distribution of latencies.

For paired presentation (see Tables 4 and 5), latencies were reliably related to the numeric distance between a flanker and the target immediately preceding it, at 200-ms and at 500-ms RSI ($\underline{R}^2$ = .11 and $\underline{R}^2$ = .08). For unit increases in distance between the previous target and the subsequent flanker, RTs decreased by 5 ms at 200-ms RSI and decreased by 4 ms at 500-ms RSI. The variance uniquely accounted for by this factor was 5%

200-ms and 500-ms RSI, respectively. Residuals do not appear to deviate from linearity. Responding to the previous target seems to interfere with the suppression of distracting information on the subsequent trial. Slower suppression results in slower processing of the correct response if the flanker on the subsequent trial is closely related to the previous target, as opposed to more remotely related. No factors accounted for error rates reliably at either delay.

2040-ms RSI. Only results for paired presentation are available at this delay (see Table 6). The results for latencies obtained with paired presentation were similar to those reported for 200-ms and 500-ms RSIs (R^2 = .13). For unit increases in distance between the previous target and the subsequent flanker, latencies decrease by 4 ms. The variance uniquely accounted by the numeric distance between a flanker and the target preceding it was 4%, and plots of residuals approached linearity.

For error rates, the cross-relations factors were statistically reliable (R^2 = .06). The numeric distances between a target and the flanker preceding it

and between a flanker and the target that preceded it both decreased the proportion of errors as a function of distance between the digits ($\underline{b}$ = -1.6% and $\underline{b}$ = -1.7%), and each accounted for 3% of the variance of error rates. The regression results for error rates in no way compromise the results obtained with latencies because regression weights for latencies and error rates are of the same sign. The distribution of residuals as a function of predictors approaches linearity for both error rates and latencies.

As mentioned previously, the multiple $\underline{R}^2$s were generally low, not exceeding .12. This result is slightly alarming because of the large amount of variance left unexplained once the independent variables are entered in the regressions. To determine whether the measures used were reliable, coefficients of equivalence were computed for both presentation formats. Coefficients of equivalence are correlations between the data obtained with half of the participants and data obtained with the other half. If the correlation between latencies for both groups is statistically significant, then the dependent measure is considered

reliable (Brown, 1976). The magnitude of the correlation is inversely related to the amount of variability in the measure.

For continuous presentation, the coefficients were not reliable, except at 500-ms RSI (r = .37, p < .001). The coefficients of equivalence for paired presentation were .36, .35, .45, and .51 (ps < .001) for 40-ms, 200-ms, 500-ms, and 2040-ms RSIs, respectively. These results indicate that the obtained measures for continuous presentation generally are not very reliable. Given that the coefficients of equivalence are fairly low, the obtained multiple R^2s are not trivial for the independent variables used in this study.

Interference Observed Through Intrusion Errors

A related question is whether errors can be explained directly by numeric distances between digits presented on a trial or indirectly by other distances between consecutive trials. Of the error trials not eliminated because of equipment malfunction, those for which a digit other than the target was named and those for which initial utterances were incompatible with initial vocalization for a correct response (e.g.,

saying "Tee-nine" for "9") were coded as intrusion errors. These trials also were coded in terms of the possible source of intrusion (i.e., which digit could have led to the utterance). These first utterances were compared to the first vocalizations necessary to say any of the four digits presented on consecutive trials. If the utterance matched the initial vocalization of any of these digits, then the error was assumed to be a direct result of this digit. For example, a erroneous response like "Nah-six" would be categorized as originating from the digit "9" presented as either target or flanker on the previous trial or the flanker on the current trial. Intrusion errors were categorized as originating from the current flanker, the previous flanker, or the previous target. Any errors that could not be categorized unambiguously were coded as "Ambiguous" (1.4% of all intrusion errors).

Inspection of the distribution of errors as a function of the source of intrusion indicates that most of the unambiguous intrusions were directly attributable to the flanker on the target trial (see Table 7). For continuous presentation, the flanker accounted for more

than 60% of errors with an identifiable source. For paired presentation trials, the flanker was the source of error for more than 80% of the errors with a clearly identified source. These results indicate that the task is characterized by features similar to Stroop-like tasks. Inaccurate responses reflect confusion between the target and the current flanker.

Discussion

The purpose of this research was to determine whether semantic or associative relatedness influences the two retrieval mechanisms proposed by Neill and Westberry (1987) and, if so, in what way. The results of this study can be summarized briefly. First, the time to name a target varies as an inverse function of the numeric distance between its accompanying flanker and the previous target. This effect indicates that target activation is influenced by at least one intertrial factor investigated in this study and that activation is sensitive to semantic or associative relatedness between the digits involved. Second, erroneous responses appear to reflect intrusion of the current flanker on the identification of the target.

Such a result supports the assumption that the task shares some features with more typical color-word, Stroop-like tasks.

What remains to be answered is how target activation and distractor suppression can account for these results. This issue is addressed separately for the variables initially counterbalanced by design (i.e., between targets, between flankers, and between digits on the current trial) and for those left to vary (i.e., cross-relations). The implications of the observed effects and their interpretations are integrated in a model that accounts for the present results and for previous results obtained by researchers interested in intertrial influences.

Variables Counterbalanced by Design

The reported experiment initially was designed to examine semantic or associative relatedness between consecutive targets, between consecutive flankers, and between digits presented on a single trial. These factors were examined because Neill (1977, 1978; Neill & Westberry, 1987) did not investigate them in his studies. For the present study, it seemed important to

assess whether other factors between consecutive stimuli could be responsible for the reported results and to eliminate any possibilities that these factors are not influential.

The fact that most of the regression analyses on latencies and error rates did not yield statistically reliable effects of these numeric distances suggests that they do not influence the retrieval mechanisms proposed by Neill. The only exception is observed with latencies at 40-ms RSI with continuous presentation: The target on the second trial is more rapidly identified if the previous target is closely related than more remotely related. This result could suggest that activation from the previous target spreads to closely related concepts. If spread of activation is the basis of this effect, then facilitation effects also should have been obtained with paired presentation at 40-ms RSI. This result was not obtained. In fact, effects of numeric distance between consecutive targets were not obtained in any other condition than continuous presentation at 40-ms RSI. Given this inconsistency in the data, any conclusions based on the apparent effect

of distance between successive target must be qualified until the result is replicated.

Semantic relatedness of the variables counterbalanced by design does not appear, in general, to influence selection and retrieval mechanisms. Intrusion errors indicate that confusion in the selection of information arises between simultaneously presented targets and flankers. This result suggests that activation levels between target and flanker on a given trial are potentially indiscriminable. Thus, selection of a response is difficult, in some cases resulting in the flanker being selected as the response.

The lack of effects due to semantic or associative relatedness between simultaneously presented digits implies that the contribution of each digit to the other digit's activation level is reciprocal. More precisely, any influence exerted by the representation of one digit on the activation level of the other is counteracted by equal influence from the latter concept on the former's activation. The indiscriminability of target and flanker activation leads to greater possibility of wrongful selection for retrieval.

In summary, the general null effects of the regression analyses with the counterbalanced variables indicate that semantic or associative relatedness does not play a role important enough to warrant concern when dealing with a Stroop-like task. The cross-relations, however, appear to be of greater import to understand the retrieval mechanisms investigated in this study.

Variables of Relevance to the Retrieval Mechanisms

The variables in the present study that correspond to the factors investigated by Neill (1977, 1978; Neill & Westberry, 1987) were the two cross-relations. These relations could not be perfectly counterbalanced without confounding other variables to some extent, so they were left to vary. Nevertheless, the importance of the cross-relations cannot be ignored because they could involve effects directly attributable to the two retrieval mechanisms proposed by Neill.

Neill and Westberry (1987) suggested that distractor suppression and target activation are involved in the retrieval of information in Stroop-like tasks. Such a conjecture would be more powerful if other intertrial influences were identified as trivial

or insignificant in terms of their influence on the activation levels of digits on the second trial. By providing evidence that other possible influences are minimal, the present study justifies a closer examination of the semantic or associative relatedness relevant to the two selection mechanisms.

The results of regression analyses on latencies indicate that target facilitation occurs under all conditions (all RSIs for both presentation formats) and is statistically reliable from 200-ms to 2040-ms RSIs with paired presentation. Neill and Westberry (1987) focused much of their attention on the distractor-suppression mechanism. In the present study, the effects of this mechanism were expected to vary directly as a function of the numeric distance between a target and the flanker immediately preceding it (F_1T_2). No such effect was obtained. The only hint of an effect was observed for error rates at 40-ms and 2040-ms RSIs with paired presentation, when the data were grouped according to the magnitude of the numeric distance (i.e., small, medium, or large). These results, however, are based on very few errors and should be

interpreted with caution. Moreover, Neill and Westberry reported distractor-suppression effects with stimuli repeated from trial to trial. In the present study, the same stimuli were never repeated. Consequently, the results do not refute the existence of such an effect, but rather eliminate the possibility that semantic or associative relatedness bears on the mechanism of distractor suppression.

The effects obtained lend themselves to the possibility that target activation and distractor suppression contribute jointly to the selection and retrieval of a target. Target activation is sensitive to semantic relatedness, but effects of distractor suppression do not spread to related concepts. Another possibility, based on a suggestion by Klein (1964), calls for comment. Klein simply required participants to name both target and distracting information in a usual Stroop task. This manipulation eliminated interference from distracting information when it was named before the target, but not when the target was named first. Klein suggested that responding to a stimulus deactivates its corresponding representation in

memory and makes it resistant to further activation for some time, so that it is less accessible for further processing--a mechanism similar to articulatory suppression (Logie & Baddeley, 1987). Suppression by articulation is thought to have localized effects in the sense that it is not expected to lead to suppressed activation of related concepts.

If, however, the effects of suppression by articulation are not localized, then target-facilitation effects observed in this study might be explained by Klein's suggestion. However, if such a mechanism was involved in the selection of information in the task, then closely related targets on the subsequent trial would also have been less accessible, resulting in greater time to name the subsequent target. This was not the case, and so the hypothesis based on Klein's suggestion must be dismissed.

An Integration

In closing, an integration of intertrial influences is presented. The proposed model accounts for the following results: (a) the effects of numeric distance between a flanker and the preceding target is

consistently reliable across RSI, in the sense that closely related digits facilitate target identification on the second trial; (b) all other numeric distances between consecutive trials do not affect response latencies or error rates consistently; (c) performance is highly accurate at all RSIs; and (d) most errors are intrusions from the current flanker. The proposed model also provides an explanantion of Neill and Westberry's (1987) finding that distractor suppression increases with longer RSIs up to 500-ms RSI and decreases thereafter.

A step-by-step description of the proposed model facilitates the account of these effects. The presentation of the first trial of a pair of consecutive trials results in activation of concepts associated with the stimuli. For example, presenting "3 7 3" will begin activation of the concepts for 3 and 7. When activation of the flanking digits and the middle digit reach a certain level, distracting and target information are discerned in the sense that, based on location cues, one stimulus is to be selected and the other stimulus is to be ignored. Discerning

the target results in a spread of activation from the target to closely related concepts. Discerning the distractor results in suppression of activation of the concept associated with the flankers. The distinction of distracting and target information occurs before the activation level of the concepts is high enough to retrieve the verbal label required to respond. The point is that relative position information, or some other early visual cue(s), is sufficient to label one digit as the distractor and one as the target.

Suppression of distracting information continues over time, until the activation associated with the distractor reaches some undetermined level. In the meantime, target information can be selected for response. The model requires an additional assumption to account for the lack of semantic-relatedness effect between consecutive targets. The assumption is that the response mechanism cannot be initiated until the suppression of irrelevant information has begun. Intrusion errors indicate that distracting information is sufficiently activated upon presentation to compete with target information for selection. If information

is selected for response before distracting information is sufficiently suppressed, then distracting information is nearly as likely as target information to be selected. This situation seldom occurs, as reflected by the low error rates. That accuracy is very high suggests that suppression is initiated early in the processing sequence. This description of suppression and activation accounts (a) for intrusion errors originating from the current flanker and (b) for low error rates obtained with short RSIs. This model of suppression also accounts for increasing interference up to 500-ms RSI obtained by Neill and Westberry (1987).

To account for the decrease in interference after 500-ms RSI in Neill and Westberry's (1987) study, the effects of suppression must have to decay once some maximal level of suppression has been reached. The results of the present study suggest that the distractor-suppression mechanism proposed by Neill and Westberry (1987) is not affected by semantic relatedness. To fit the results of the present study with those of Neill and Westberry, distractor

suppression must be postulated to affect only the activation of distracting information in the sense that suppression does not spread to related concepts.

In contrast, target activation increases the activation level of semantically related concepts and, thus, facilitates their processing on the subsequent trial. This interpretation is supported by the fact that facilitation effects obtained between a flanker and the target immedately preceding varied as an inverse function of numeric distance. More precisely, distracting information closely related to a previous target can be processed more rapidly than remotely related information, leading to faster onset of suppression and faster access to the target to be retrieved.

If activation of a target spreads to closely related concepts, then targets on a subsequent trial should be influenced by semantic relatedness similar to effects observed with distracting information on a subsequent trial. Such was not the case. Activation of a target is necessary but not sufficient for accurate selection because activation of irrelevant information

could disturb the selection process. Instead, the time to initiate suppression of distracting information determines response latency. By ensuring that highly activated distracting information is being suppressed, a response based on target information can be initiated with greater confidence. This hypothesis could be tested by presenting target and distracting information asynchronously. Presenting distracting information before target information should accelerate the time to initiate suppression, thus reducing interference effects of distractor suppression and potentially eliminating facilitation effects of closely related previous targets. This issue requires investigation.

An alternative to the suppression hypothesis is simply that, once distracting and target information have been discerned and labeled, the target is selected for response. Labeling would be sufficient to avoid selection of irrelevant information. Such an account, however, could not explain the initial increase in interference as a function of RSI (Neill & Westberry, 1987), unless the label is assumed not be effective immediately. If such an assumption were true, then

accuracy would be low, which is not the case. Moreover, if the label is assumed to increase in efficiency and then decrease, to account for Neill and Westberry's data, then this labeling hypothesis would be functionally identical to the proposed suppression hypothesis.

The proposed model can now be summarized as follows: Presentation of stimuli activates concepts in memory and initiation of suppression of distracting information is necessary to ensure accurate selection of target information. Residual activation, including suppressed activation of distracting information, remains available when a subsequent trial is presented. The accumulation of residual activation and activation from presentation of a subsequent trial facilitates the processing of this latter information.

In summary, the activation level of information presented on a trial appears to be influenced by residual activation from a previous trial. The influence of this residual activation affects processing of the subsequent trial in different ways depending on the time allowed after a response is given, on the

relations between consecutive trials, and on task characteristics. Many issues still remain unanswered. For example, if suppression is the limiting mechanism, then preexposing distracting information in a similar task should reduce the time necessary to initiate suppression. Target activation and distractor suppression should interact when information is repeated from trial to trial. The results of this study mandate a closer examination of the effects of previous response selection on processing subsequent information. Intertrial influences in selective attention tasks might provide cognitive researchers with a better understanding of the decision process involved in such tasks.

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Footnotes

[1] Once two numeric relations have been assigned, a third one is determined. For example, if $W_{2-2} = 9$ and $T_{1-2} = 4$, then $T_1F_2 = 5$. Similarly, if $W_{2-2} = 9$ and $F_{1-2} = 4$, then $F_1T_2 = 5$.

[2] Flowers and Wilcox (1982) found that differences between facilitative and interfering effects were maximized with spatial separation of approximately 1.0 degree of visual angle between digits.

Table 1

Examples of Consecutive Trials for Conditions Used by Neill (1978) and Neill and Westberry (1987)

Condition	Trial	Distractor (word)	Target (color)	Mean RT
Neill(1978)				
$Target_1$=$Distractor_2$	1	Red	Blue	
	2	Blue	Green	695 ms[a]
Unrelated	1	Red	Yellow	
	2	Blue	Green	715 ms
Neill and Westberry (1987)				
$Distractor_1$=$Target_2$[b]	1	Green	Blue	
	2	Red	Green	862 ms[c]
Unrelated	1	Yellow	Blue	
	2	Red	Green	839 ms

[a] Target trials were presented immediately upon response to the previous trial (RSI = 0 ms).

[b] The subscript indicates the trial number on which the information was repeated.

[c] The mean RTs are those of 520-ms RSI, for which maximum suppression was obtained.

Table 2

Correlations Among Independent Variables Based on Actual Numeric Distances

RSI (ms)		Paired Presentation				Continuous Presentation			
		T_{1-2}	F_{1-2}	T_1F_2	F_1T_2	T_{1-2}	F_{1-2}	T_1F_2	F_1T_2
40	W_{2-2}	-.13	-.13	.12	.12	-.09	-.11	.09	.07
	T_{1-2}		.11	.09	.09		.08	.06	.08
	F_{1-2}			.09	.09			.10	.04
	T_1F_2				-.43***				-.33***
200	W_{2-2}	-.12	-.12	.10	.10	-.04	-.07	.06	.10
	T_{1-2}		.05	.05	.04		-.00	-.03	.06
	F_{1-2}			.05	.06			.05	.03
	T_1F_2				-.42***				-.36***
500	W_{2-2}	-.15	-.15	.08	.08	-.09	-.09	.10	.12
	T_{1-2}		.09	.03	.09		-.05	.05	.05
	F_{1-2}			.09	.03			.08	.01
	T_1F_2				-.39***				-.39***
2040	W_{2-2}	-.15	-.15	.10	.10				
	T_{1-2}		.13	.08	.11				
	F_{1-2}			.11	.08				

T_1F_2	$-.46^{***}$

*** $p < .001$

Table 3

Regression Summary With Actual Distances at 40-ms RSI

	Latencies				% Error			
Predictor	r	b	SE	sr	r	b	SE	sr
Continuous Presentation[a]								
W_{2-2}	-.10	-5.4	8.0	-.06	-.002	0.0	0.3	.01
T_{1-2}	.18*	17.4*	8.5	.17	-.001	0.1	0.3	.01
F_{1-2}	.17*	14.9+	8.5	.15	-.09	-0.3	0.3	-.07
T_1F_2	-.16*	-12.2+	6.5	-.16	.12+	0.1	0.3	.04
F_1T_2	.11	2.0	6.4	.03	-.25**	-0.6*	0.3	-.21
Paired Presentation[b]								
W_{2-2}	-.14+	-3.3	2.3	-.12	.05	1.8	1.6	.10
T_{1-2}	-.03	-1.5	2.4	-.06	.08	2.0	1.6	.11
F_{1-2}	.11	2.8	2.4	.10	.09	2.1	1.6	.11
T_1F_2	-.23**	-3.2+	1.9	-.15	.001	-1.4	1.3	-.09
F_1T_2	.17*	2.2	1.9	.10	-.12+	-2.4+	1.3	-.16

Note. r is the simple correlation between independent and dependent measures with 130 and 124 degrees of

freedom for continuous and paired presentation respectively, b is the unstandardized regression coefficient in the multiple regression, SE is the standard error of b, and sr is the semipartial correlation coefficient.

[a] $R_{latency}^2 = .09$. $F(5,126) = 2.6$, $p < .05$

$R_{error}^2 = .07$, $F(5,126) = 1.9$

[b] $R_{latency}^2 = .09$, $F(5,120) = 2.4$, $p < .05$

$R_{error}^2 = .05$, $F(5,120) = 1.3$

** $p < .01$, * $p < .05$, + $p < .10$

Table 4

Regression Summary With Actual Distances at 200-ms RSI

	Latencies				% Error			
Predictor	r	b	SE	sr	r	b	SE	sr
Continuous Presentation[a]								
W_{2-2}	-.00	3.8	8.9	.04	-.08	-0.3	.36	-.07
T_{1-2}	.02	4.4	9.4	.04	.05	0.2	.37	.05
F_{1-2}	.01	2.9	9.6	.03	.00	0.1	.38	.00
T_1F_2	-.18*	-18.8**	7.2	-.23	.05	0.4	.29	.01
F_1T_2	-.07	-13.0+	7.3	-.16	-.12+	-0.4	.29	-.11
Paired Presentation[b]								
W_{2-2}	-.03	-0.8	2.2	-.03	.06	0.9	1.5	.05
T_{1-2}	-.09	-1.9	2.4	-.07	-.15*	-2.1	1.5	-.12
F_{1-2}	-.12+	-3.2	2.4	-.12	-.13+	-1.7	1.5	-.10
T_1F_2	-.29***	-4.7*	1.8	-.23	-.08	-1.4	1.1	-.11
F_1T_2	.16*	1.1	1.8	.06	-.07	-1.3	1.1	-.10

Note. r with 128 and 117 degrees of freedom for continuous and paired presentation respectively.

[a] $R_{latency}^2 = .06$, $F(5,124) = 1.5$

$R_{error}^2 = .02$, $F(5,124) = 0.6$

[b] $R_{latency}^2 = .11$, $F(5,113) = 2.7$, $p < .05$

$R_{error}^2 = .05$, $F(5,113) = 1.3$

** $p < .01$, * $p < .05$, + $p < .10$

Table 5

Regression Summary With Actual Distances at 500-ms RSI

	Latencies				% Error			
Predictor	r	b	SE	sr	r	b	SE	sr
Continuous Presentation[a]								
W_{2-2}	-.11	-14.4	9.5	-.13	.03	0.3	.47	.06
T_{1-2}	-.03	-4.9	9.1	-.05	-.07	-0.2	.45	-.04
F_{1-2}	.07	5.6	9.1	.05	.08	0.5	.45	.09
T_1F_2	.12^{+}	13.1^{+}	7.6	.15	-.07	-0.5	.37	-.11
F_1T_2	-.01	5.1	7.4	.06	-.05	-0.4	.36	-.09
Paired Presentation[b]								
W_{2-2}	-.10	-3.0	2.5	-.10	-.08	-0.9	1.1	-.07
T_{1-2}	-.06	-1.8	2.4	-.06	.08	1.0	1.1	.08
F_{1-2}	-.08	-2.0	2.4	-.07	-.03	-0.6	1.1	-.05
T_1F_2	-.25**	-3.9*	1.9	-.17	.09	0.5	0.9	.05
F_1T_2	.15*	1.9	1.9	.08	-.14^{+}	-1.0	0.9	-.10

Note. r with 136 and 133 degrees of freedom for continuous and paired presentation respectively.

[a] $R_{latency}^2 = .04$, $F(5,132) = 1.1$

$R_{error}^2 = .03$, $F(5,132) = 0.7$

[b] $R_{latency}^2 = .08$, $F(5,129) = 2.2$, $p = .05$

$R_{error}^2 = .04$, $F(5,129) = 0.9$

** $p < .01$, * $p < .05$, + $p < .10$

Table 6

Regression Summary With Actual Distances at 2040-ms RSI for Paired Presentation

	Latencies				% Error			
Predictor	r	b	SE	sr	r	b	SE	sr
W_{2-2}	-.07	-1.4	1.7	-.06	-.01	0.2	1.0	.02
T_{1-2}	.00	-0.3	1.7	-.01	-.10^{+}	-0.7	0.9	-.05
F_{1-2}	.03	0.8	1.7	.03	-.10^{+}	-0.7	0.9	-.06
T_1F_2	-.32***	-3.6**	1.3	-.20	-.13*	-1.7*	0.7	-.18
F_1T_2	.27**	2.5^{+}	1.3	.14	-.11^{+}	-1.6*	0.7	-.17

Note. r with 172 degrees of freedom.

$R_{latency}^2 = .13$, $F(5,168) = 4.8$, $p < .001$

$R_{error}^2 = .06$, $F(5,168) = 2.2$, $p = .05$

** $p < .01$, * $p < .05$, + $p < .10$

Table 7

Percentage Error, Categorized by Error Type, as a Function of RSI

RSI (ms)	Sources of Error			
	Current Flanker	Previous Target	Previous Flanker	Ambiguous
Continuous Presentation				
40	0.82 (62.1)	0.25 (18.9)	0.25 (18.9)	0.82
200	0.92 (73.0)	0.17 (13.5)	0.17 (13.5)	1.09
500	1.78 (82.0)	0.08 (3.7)	0.31 (14.3)	1.62
Paired Presentation				
40	2.55 (91.4)	0.00 (0.0)	0.24 (8.6)	1.51
200	2.01 (86.3)	0.00 (0.0)	0.32 (13.7)	1.21
500	2.35 (81.0)	0.32 (11.0)	0.23 (7.9)	1.64
2040	2.42 (83.4)	0.11 (3.8)	0.37 (12.8)	1.63

Note. The numbers in parentheses are percentages of unambiguously coded errors.

Appendix 1

Correlations Among Grouped Independent Variables as a Function of RSI

RSI(ms)		Paired Presentation				Continuous Presentation			
		T_{1-2}	F_{1-2}	TF_{1-2}	FT_{1-2}	T_{1-2}	F_{1-2}	TF_{1-2}	FT_{1-2}
40	W_{2-2}	-.11	-.11	.02	.02	-.06	-.08	-.03	.00
	T_{1-2}		.07	.07	.07		.00	.06	.05
	F_{1-2}			.07	.07			.03	.07
	TF_{1-2}				-.35***				-.25**
200	W_{2-2}	-.07	-.07	.02	.02	.02	.00	.03	.01
	T_{1-2}		.02	-.04	.00		-.00	-.04	-.01
	F_{1-2}			.00	-.04			.00	-.06
	TF_{1-2}				-.38***				-.31***
500	W_{2-2}	-.15*	-.15*	.02	.02	-.07	-.07	.06	.03
	T_{1-2}		.07	.01	.01		-.08	-.00	-.00
	F_{1-2}			.01	.01			-.04	.03
	TF_{1-2}				-.36***				-.35***
2040	W_{2-2}	-.15*	-.15*	.04	.04				
	T_{1-2}		.12	.04	.05				
	F_{1-2}			.05	.04				

TF_{1-2}	$-.40^{***}$

*** $p < .001$, ** $p < .01$, * $p < .05$

Appendix 2-A

Regression Summary With Grouped Independent Variables as a Function of RSI for Paired Presentation

	Latencies				% Error			
Predictor	r	b	SE	sr	r	b	SE	sr
RSI 40 ms[a]								
W_{2-2}	-.07	-8.2	10.6	-.07	.03	2.1	2.8	.06
T_{1-2}	.00	-2.8	10.7	-.02	.14+	5.0	2.9	.14
F_{1-2}	.14+	15.2	10.7	.12	.14+	5.1+	2.9	.15
T_1F_2	-.11	-5.2	8.4	-.05	-.04	-3.1	2.3	-.12
F_1T_2	.20*	15.1+	8.4	.16	-.14*	-4.9*	2.3	-.18
RSI 200 ms[b]								
W_{2-2}	-.05	-2.8	4.3	-.06	.05	1.0	2.7	.03
T_{1-2}	-.06	-3.6	4.6	-.07	-.13+	-3.9	2.8	-.13
F_{1-2}	-.09	-4.3	4.6	-.08	-.11	-3.3	2.7	-.11
T_1F_2	-.20*	-6.0+	3.5	-.15	-.05	-1.9	2.1	-.08
F_1T_2	.15*	3.1	3.5	.08	-.04	-1.6	2.1	-.07
RSI 500 ms[c]								
W_{2-2}	-.02	-1.7	4.9	-.03	-.03	-0.6	2.0	-.02

T_{1-2}	-.03	-1.6	4.7	-.03	.06	1.4	2.0	.06
F_{1-2}	-.08	-4.3	4.7	-.08	-.05	-1.3	2.0	-.06
T_1F_2	-.27**	-9.9*	3.8	-.22	.12+	1.5	1.6	.08
F_1T_2	.19*	4.5	3.8	.10	-.11+	-1.4	1.6	-.08
RSI 2040 ms[d]								
W_{2-2}	-.10	-4.2	3.4	-.09	.01	0.3	1.7	.02
T_{1-2}	.02	0.3	3.3	.01	-.06	-0.7	1.7	-.03
F_{1-2}	.00	-0.4	3.3	-.01	-.07	-1.1	1.7	-.05
T_1F_2	-.29**	-7.5**	2.5	-.29	-.15*	-3.4**	1.3	-.21
F_1T_2	.22**	4.0	2.5	.11	-.11+	-3.2*	1.3	-.18

---

[a] $R_{latency}^2 = .06$, $F(5,121) = 1.6$

$R_{error}^2 = .08$, $F(5,121) = 2.1$, $p < .10$

[b] $R_{latency}^2 = .06$, $F(5,114) = 1.5$

$R_{error}^2 = .04$, $F(5,114) = 0.9$

[c] $R_{latency}^2 = .09$, $F(5,130) = 2.6$, $p < .05$

$R_{error}^2 = .03$, $F(5,130) = 0.7$

[d] $R_{latency}^2 = .11$, $F(5,169) = 4.0$, $p < .01$

$R_{error}^2 = .06$, $F(5,169) = 2.3$, $p < .05$

** $p < .01$, * $p < .05$, + $p < .10$

Appendix 2-B

Summary of Multiple Regression With Logarithmically Transformed Independent Variables as a Function of RSI for Paired Presentation

	Latencies			% Error		
Predictor	r	β	sr	r	β	sr
RSI 40 ms[a]						
W_{2-2}	-.03	-0.01	-.01	.05	0.07	.07
T_{1-2}	.04	0.01	.01	.10	0.10	.10
F_{1-2}	.15*	0.15+	.15	.10	0.10	.10
T_1F_2	-.12+	-0.08	-.07	.01	-0.04	-.03
F_1T_2	.17*	0.14	.13	-.03	-0.12	-.11
RSI 200 ms[b]						
W_{2-2}	-.01	-0.02	-.02	.13+	0.10	.10
T_{1-2}	.01	0.01	.01	-.14+	-0.13	-.13
F_{1-2}	-.14+	-0.15+	-.15	-.14+	-0.13	-.13
T_1F_2	-.17*	-0.20*	-.18	-.07	-0.13	-.12
F_1T_2	-.00	-0.08	-.08	-.06	-0.12	-.11
RSI 500 ms[c]						

W_{2-2}	-.05	-0.06	-.06	-.04	-0.41	-.04
T_{1-2}	-.00	-0.01	-.01	.09	0.91	.09
F_{1-2}	-.05	-0.06	-.05	-.04	-0.61	-.06
T_1F_2	-.25**	-0.21	-.19	.09	0.51	.05
F_1T_2	.09*	0.12	.11	-.13+	-0.11	-.11
RSI 2040 ms[d]						
W_{2-2}	-.11+	-0.10	-.09	.06	0.05	.05
T_{1-2}	.03	0.02	.02	-.06	-0.04	-.04
F_{1-2}	.03	0.04	.03	-.10	-0.08	-.08
T_1F_2	-.29**	-0.25**	-.23	-.14*	-0.23**	-.21
F_1T_2	.19**	0.09	.08	-.12+	-0.21**	-.20

Note: β represents standardized regression coefficient.

[a] $R_{latency}^2 = .06$, $F(5,121) = 1.5$

$R_{error}^2 = .03$, $F(5,121) = 0.94$

[b] $R_{latency}^2 = .05$, $F(5,115) = 1.3$

$R_{error}^2 = .07$, $F(5,115) = 1.7$

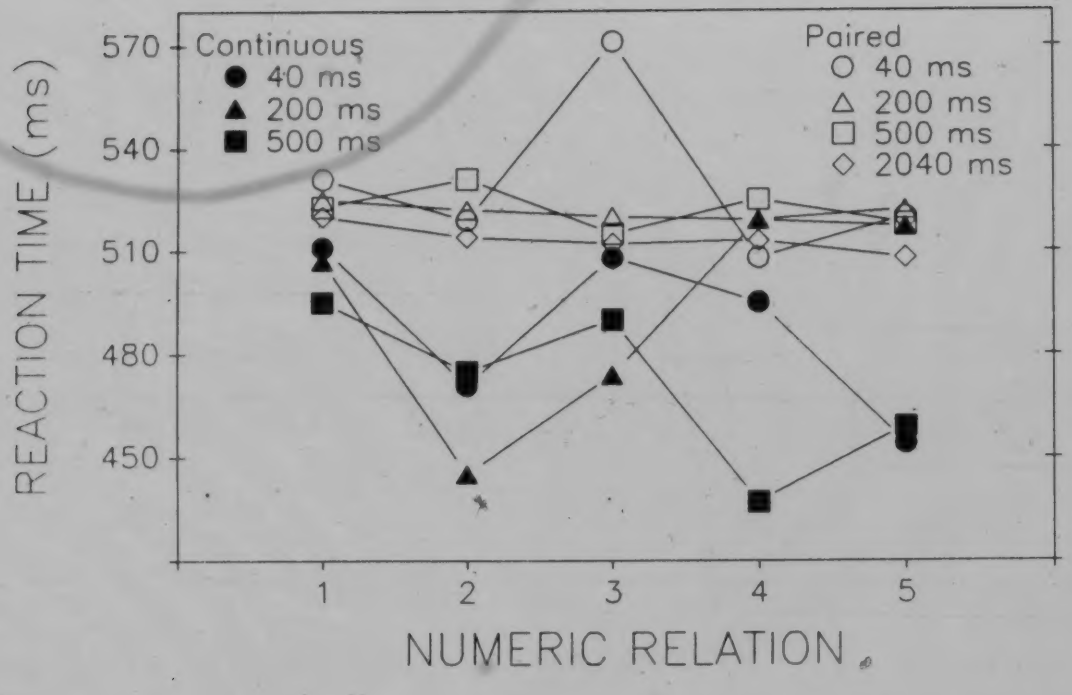
[c] $R_{latency}^2 = .08$, $F(5,130) = 2.2$, $p < .10$

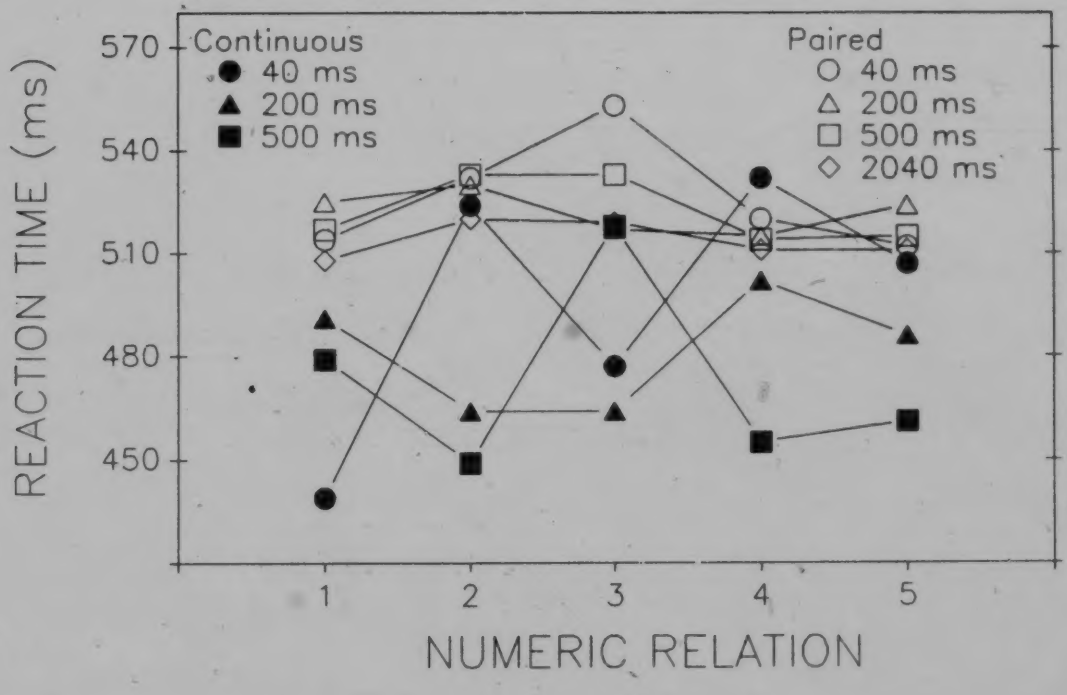
$R_{error}^2 = .03$, $F(5,130) = 0.8$

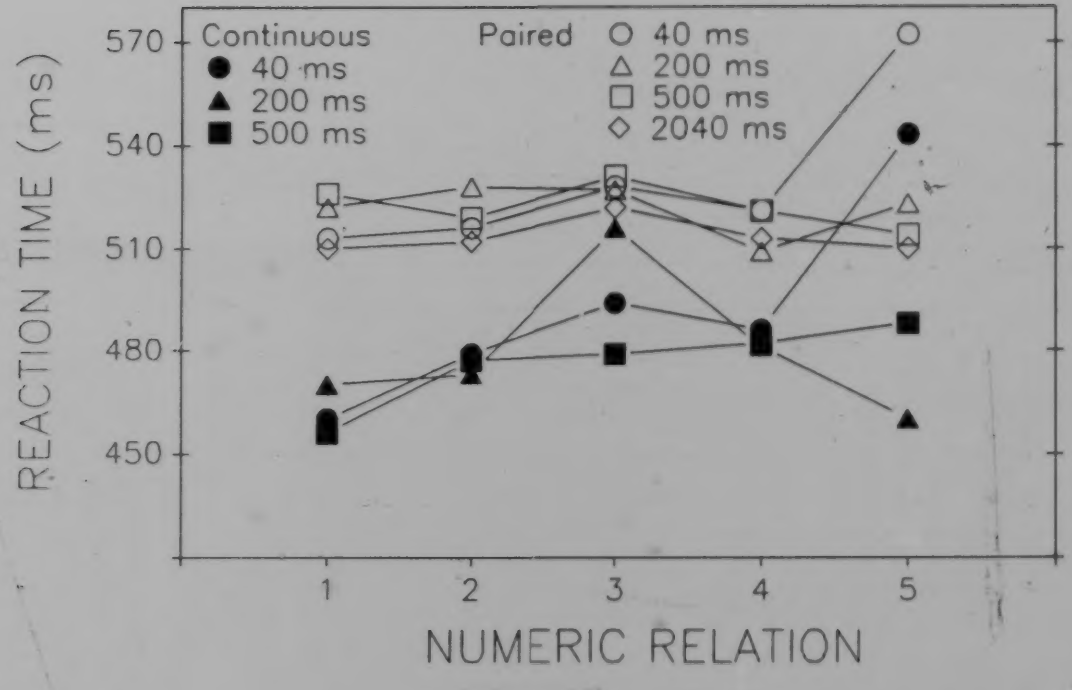
[d] $R_{latency}^2 = .10$, $F(5,169) = 3.8$, $p < .01$

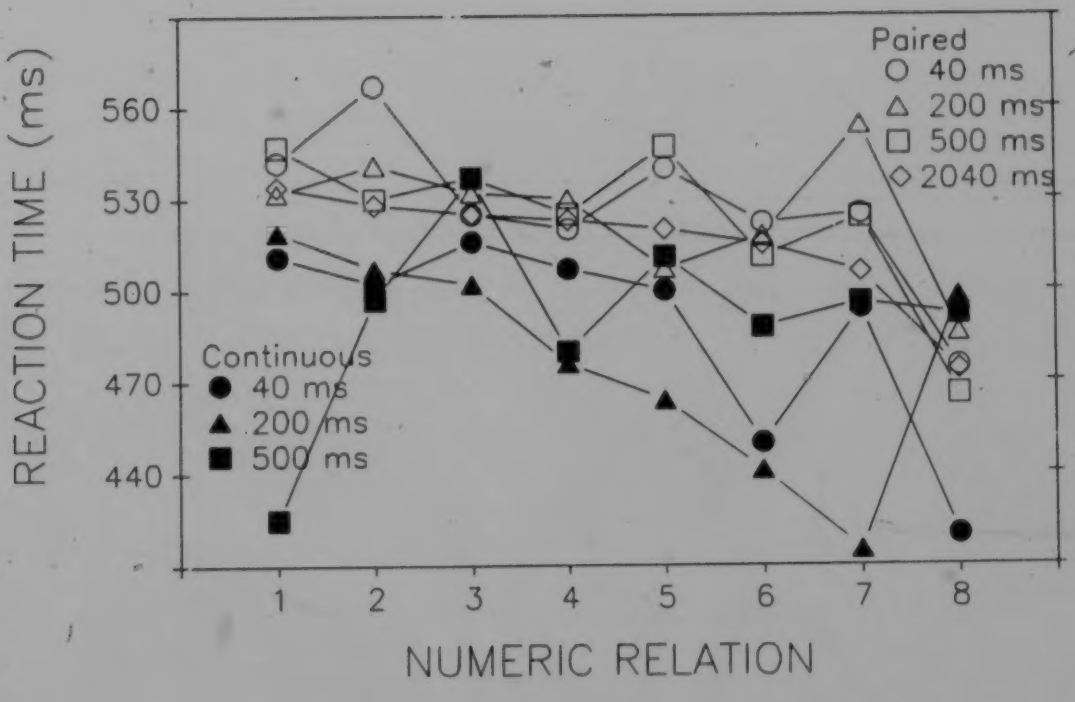
$R_{error}^2 = .07$, $F(5,169) = 2.7$, $p < .05$

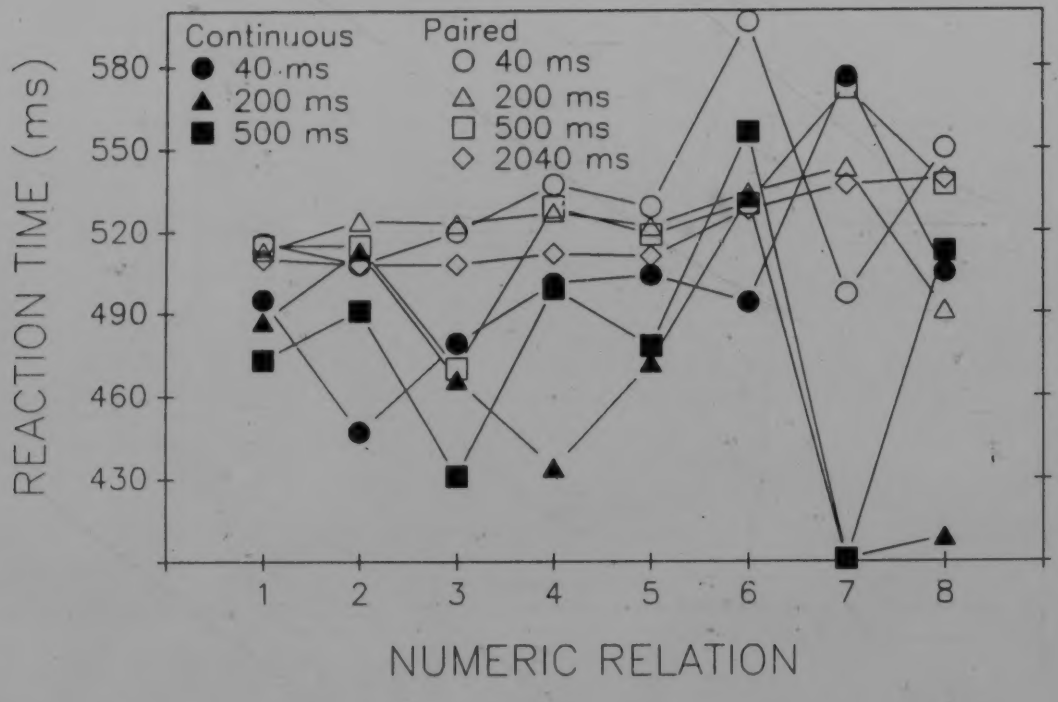
** $p < .01$, * $p < .05$, + $p < .10$


Continuous
40 ms
200 ms
500 ms
Paired
40 ms
200 ms
500 ms
2040 ms
570
540
510
480
450
REACTION TIME (ms)
1
2
3
4
5
NUMERIC RELATION


Continuous
40 ms
200 ms
500 ms
Paired
40 ms
200 ms
500 ms
2040 ms
570
540
510
480
450
REACTION TIME (ms)
1
2
3
4
5
NUMERIC RELATION


Continuous
40 ms
200 ms
500 ms
Paired
40 ms
200 ms
500 ms
2040 ms
570
540
510
480
450
REACTION TIME (ms)
1
2
3
4
5
NUMERIC RELATION


REACTION TIME (ms)
560
530
500
470
440
1
2
3
4
5
6
7
8
NUMERIC RELATION
Paired
40 ms
200 ms
500 ms
2040 ms
Continuous
40 ms
200 ms
500 ms


Continuous
40 ms
200 ms
500 ms
Paired
40 ms
200 ms
500 ms
2040 ms
REACTION TIME (ms)
580
550
520
490
460
430
1
2
3
4
5
6
7
8
NUMERIC RELATION